Creep Behavior and Durability of Cracked CMC

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Objective and Approach

Objective:

Short term: Determine creep and cyclic fatigue properties, failure modes and durability of pre-cracked 2D woven SiC/SiC composites at temperatures to 1450^0C in air.

Long term: Develop and validate physics based model to predict durability of cracked CMCs under creep and cyclic fatigue conditions in inert and oxidizing environments

Approach:

- Pre-crack CMCs at room temperature.
- Creep test pre-cracked CMCs under furnace and burner rig conditions.
- Fatigue test pre-cracked CMCs under furnace conditions.
- Analyze deformation mechanisms/ failure modes.
- If pre-cracked CMCs survive >100hr creep/fatigue tests, then measure residual in-plane tensile properties at room temperature.

Material and Characterization

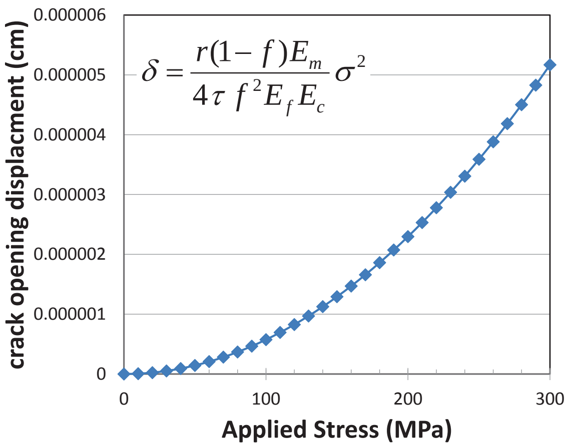
Materials and Vendors:
Fibers: Sylramic-iBN and Hi-Nicalon-S
Interface coating: CVI BN
Composites:
- **2D woven 5HS balanced melt infiltrated SiC/SiC composites (GE Composites, Delaware)**
- **2D woven 5HS balanced chemical vapor infiltrated SiC/SiC composites (Rolls-Royce High Temperature Composites Inc (Formerly Hyper-Therm HTC, Huntington Beach, CA)**

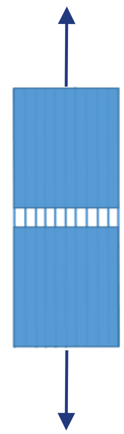
Experimental variables:
Stress: 35, 69, and 103 MPa
Temperature: 1300^{0}C and 1450^{0}C
Time: 100 to 200hrs
R ratio: 0.5
Environment: air, Burner rig
Pre-cracking stress @RT: 150-200MPa

Characterization:
Tensile, Creep, and Sustained peak low cycle fatigue (SPLCF) tests, Acoustic emission (AE) and SEM.

Factors Influencing Durability of Cracked CMCs

Predicted Crack Opening Displacement (COD) With Applied Stress for Fiber Reinforced CMCs





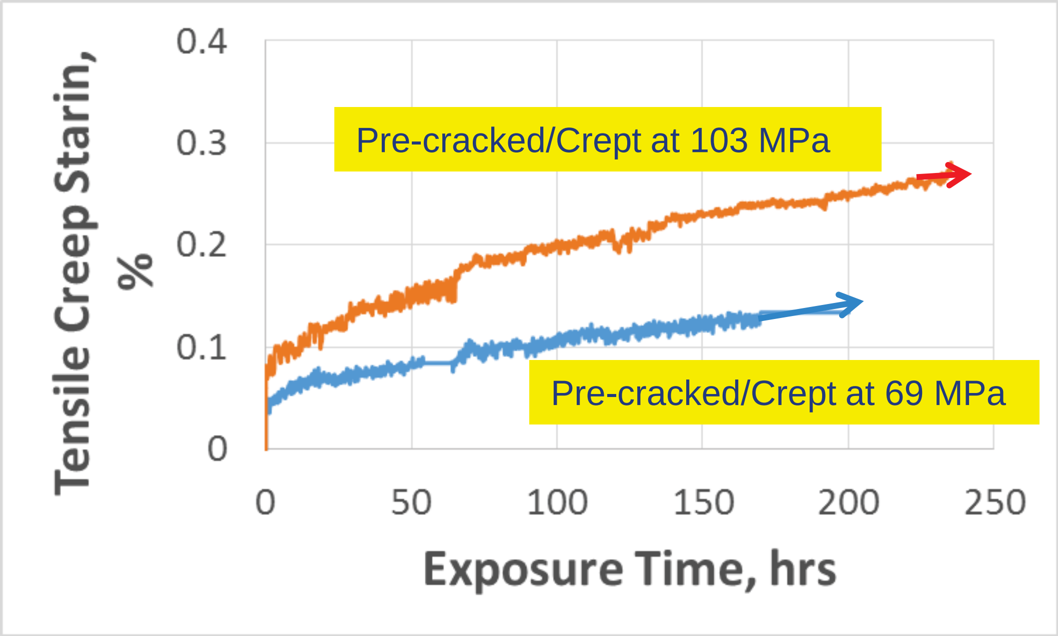
- δ = Crack opening displacement
- r = Fiber radius
- f = Fiber fraction
- E = Elastic modulus of the matrix
- E = Elastic modulus of the fiber
- E = Elastic modulus of the composite
- σ = Applied stress
- τ = Interfacial shear strength between the fiber and the matrix

- Matrix crack opening displacement
- Extant of crack
- Matrix crack healing capability
- Crack tip intensity
- Diffusivity/ permeability of oxygen
- Temperature
- Environment
- Creep/slow crack growth
- Stress
- Time
- Gas velocity
- Location of the primary crack
- Crack spacing

Marshall D.B., Cox B.N., Evans A.G., "The mechanics of matrix cracking in brittle-matrix fiber composites," Acta metall. Vol. 33, No. 11, pp 2013-2021, 1985.
Morscher G.N. and Cawley J.D., "Intermediate temperature strength degradation in SiC/SiC composites," Journal of the European Ceramic Society Vol. 22, pp 2777-2787, 2002.

Tensile Creep Behaviors of Pre-cracked 2D Balanced MI SiC/SiC Composites with Sylramic-iBN Fibers

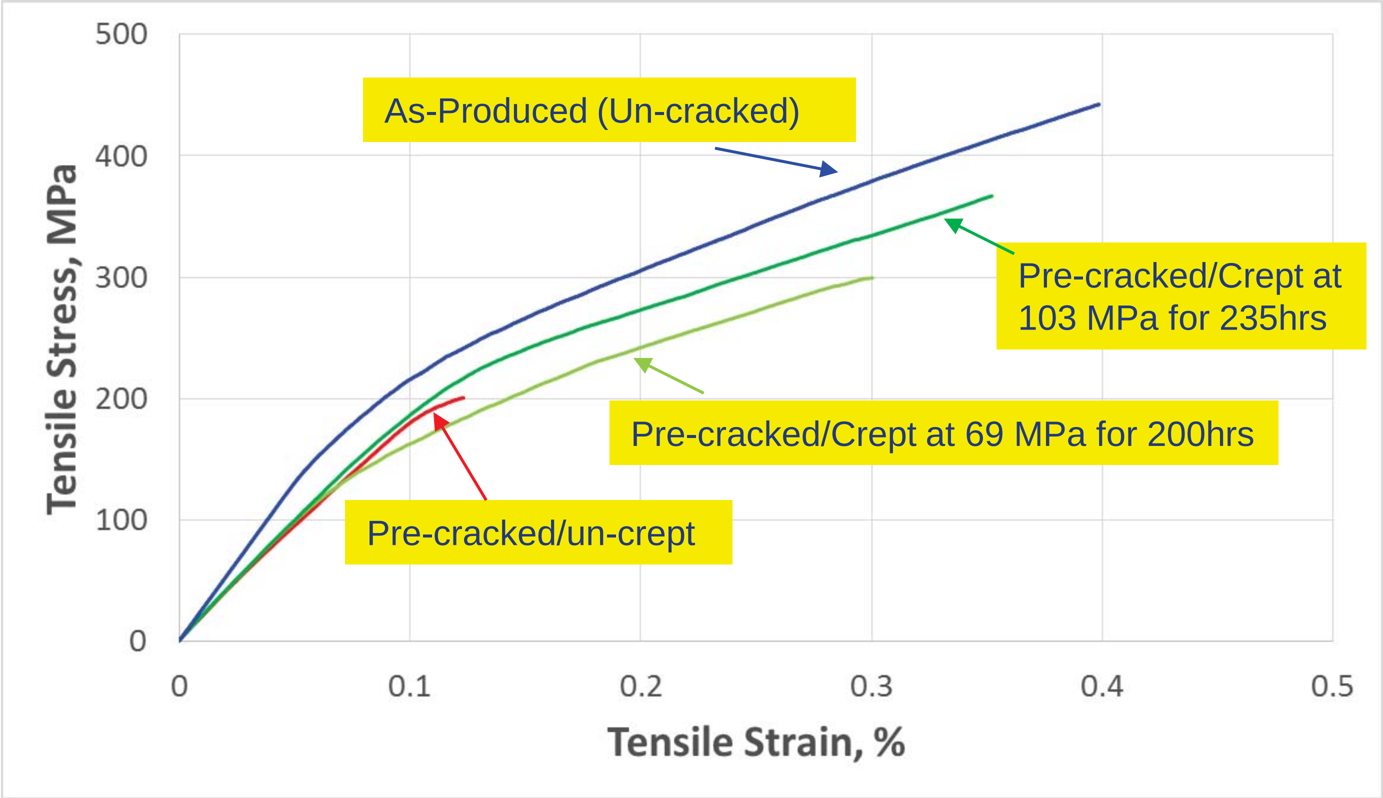
(Creep Conditions: 1315^{0}C/69 or 103 MPa /Air)



Matrix cracks in the pre-cracked MI SiC/SiC composites healed during creep testing and significantly reduced fiber oxidation. The creep curves follow fiber creep data.

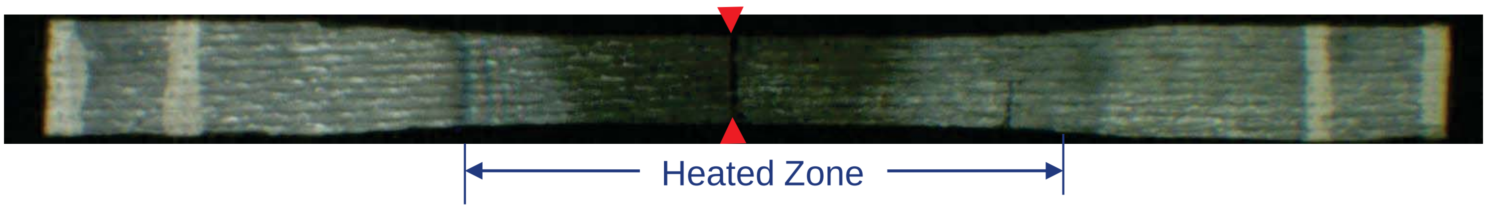
Room Temperature Tensile Stress-Strain Behaviors of Pre-cracked 2D Balanced MI SiC/SiC Composites With Sylramic-iBN Fibers Before and After Creep Test

(Creep Conditions: 1315^{0}C/69 and 103MPa /Air)

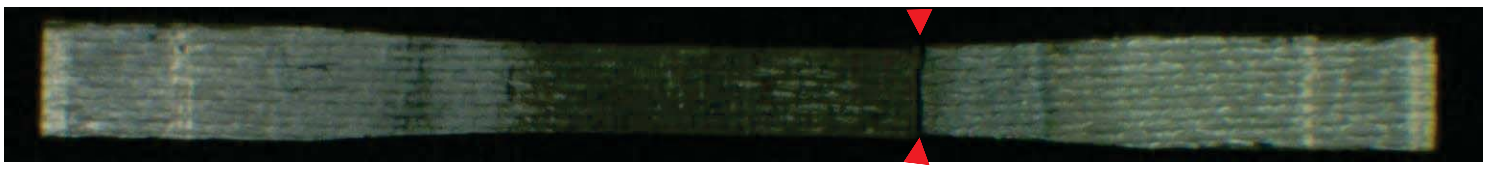


Pre-cracked and crept MI SiC/SiC composites retain > 80% of room temperature in-plane tensile properties.

Pre-cracked Uncoated MI Sylramic-iBN SiC/SiC Composite Specimens Creep Tested at 1315^{0}C for Up To 235hrs and Then Tensile Tested at Room Temperature



69MPa/200hrs

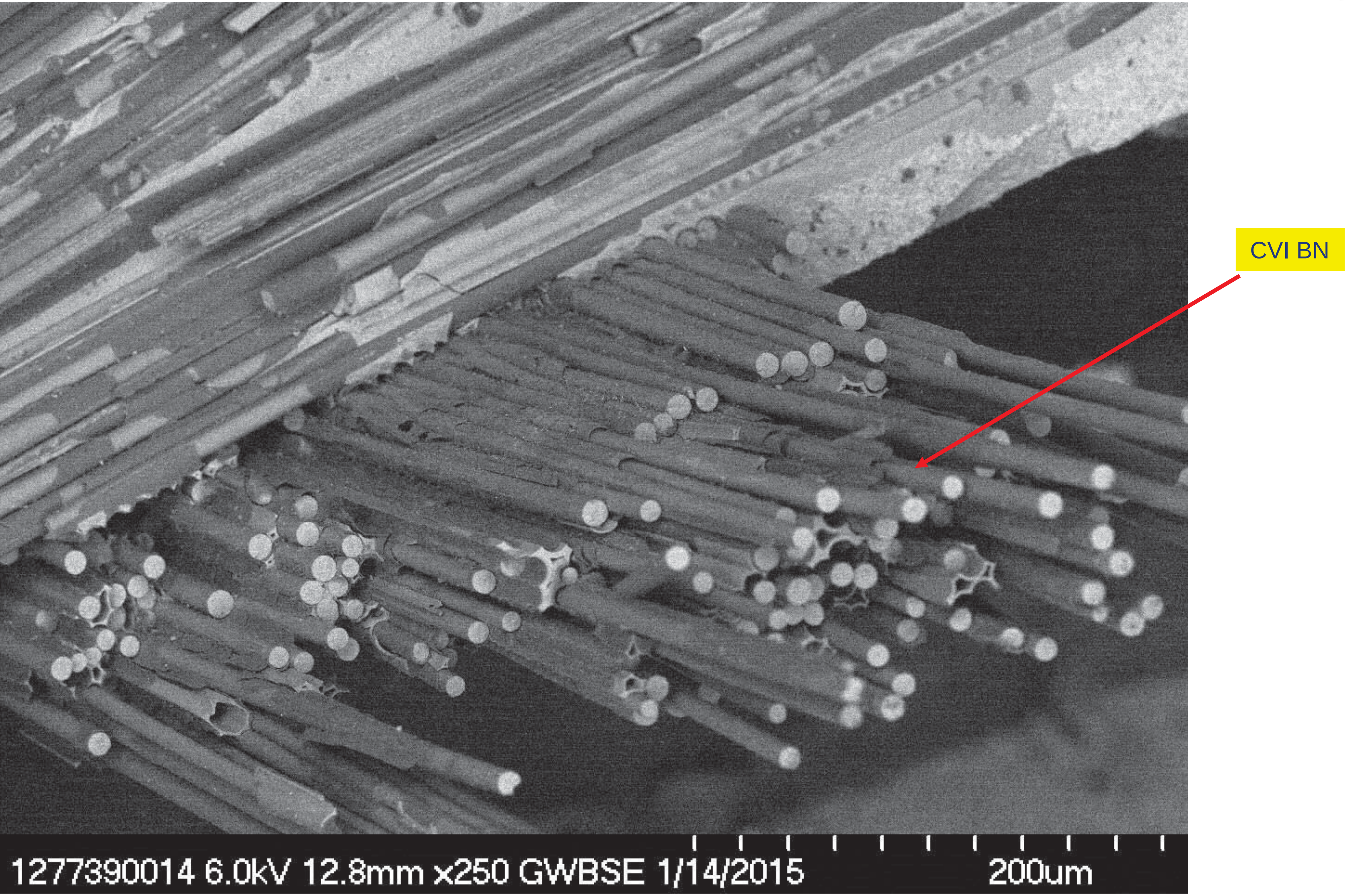


103MPa/235hrs

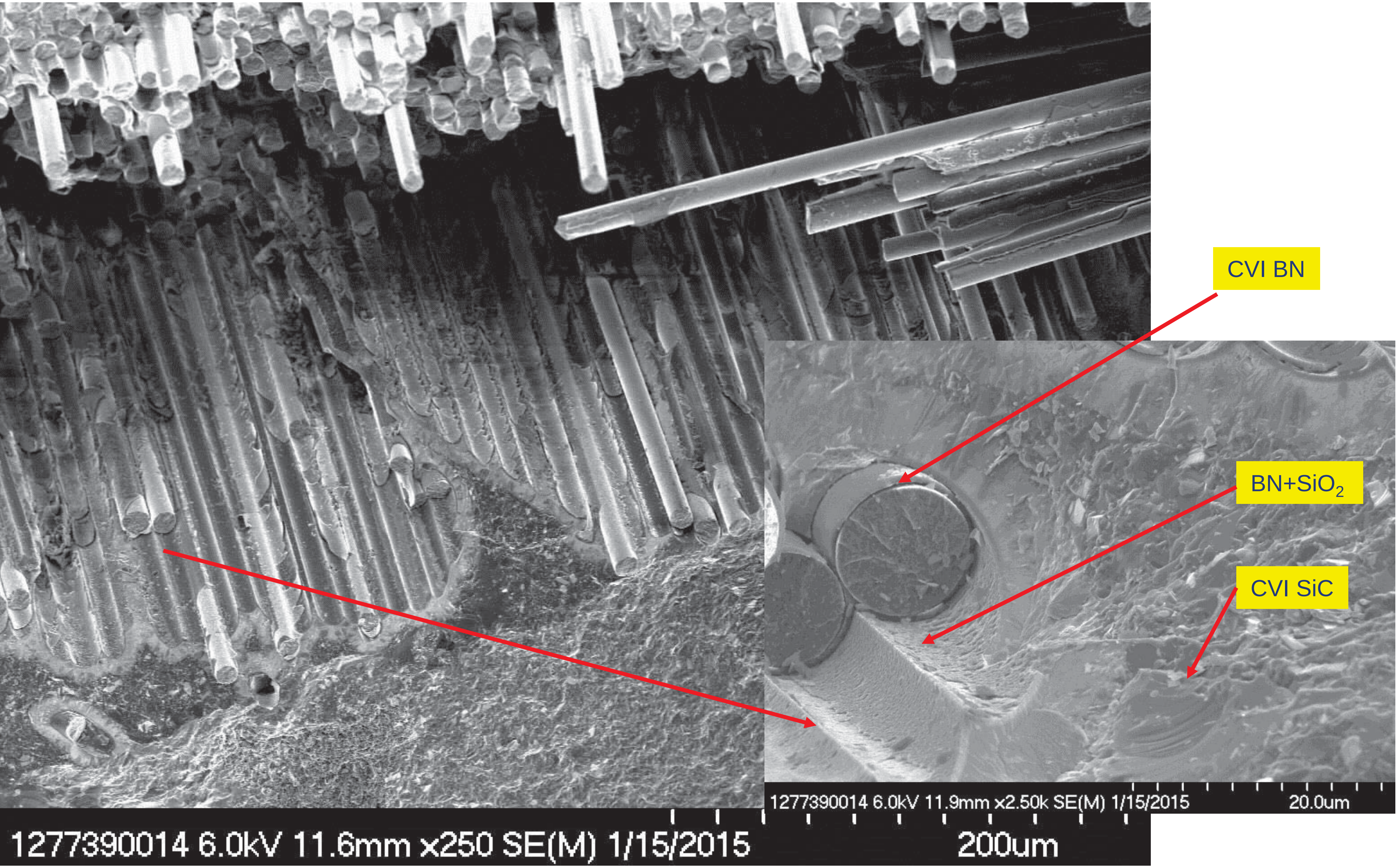
Precracked and crept MI SiC/SiC composites tensile tested at room temperature fail in the gage section. The red arrows indicate tensile fractured region.

SEM Photographs of a Pre-cracked Uncoated MI Sylramic-iBN SiC/SiC Composite Specimen Creep Tested at 1315^{0}C/103MPa/235hrs and Then Tensile Tested at Room Temperature

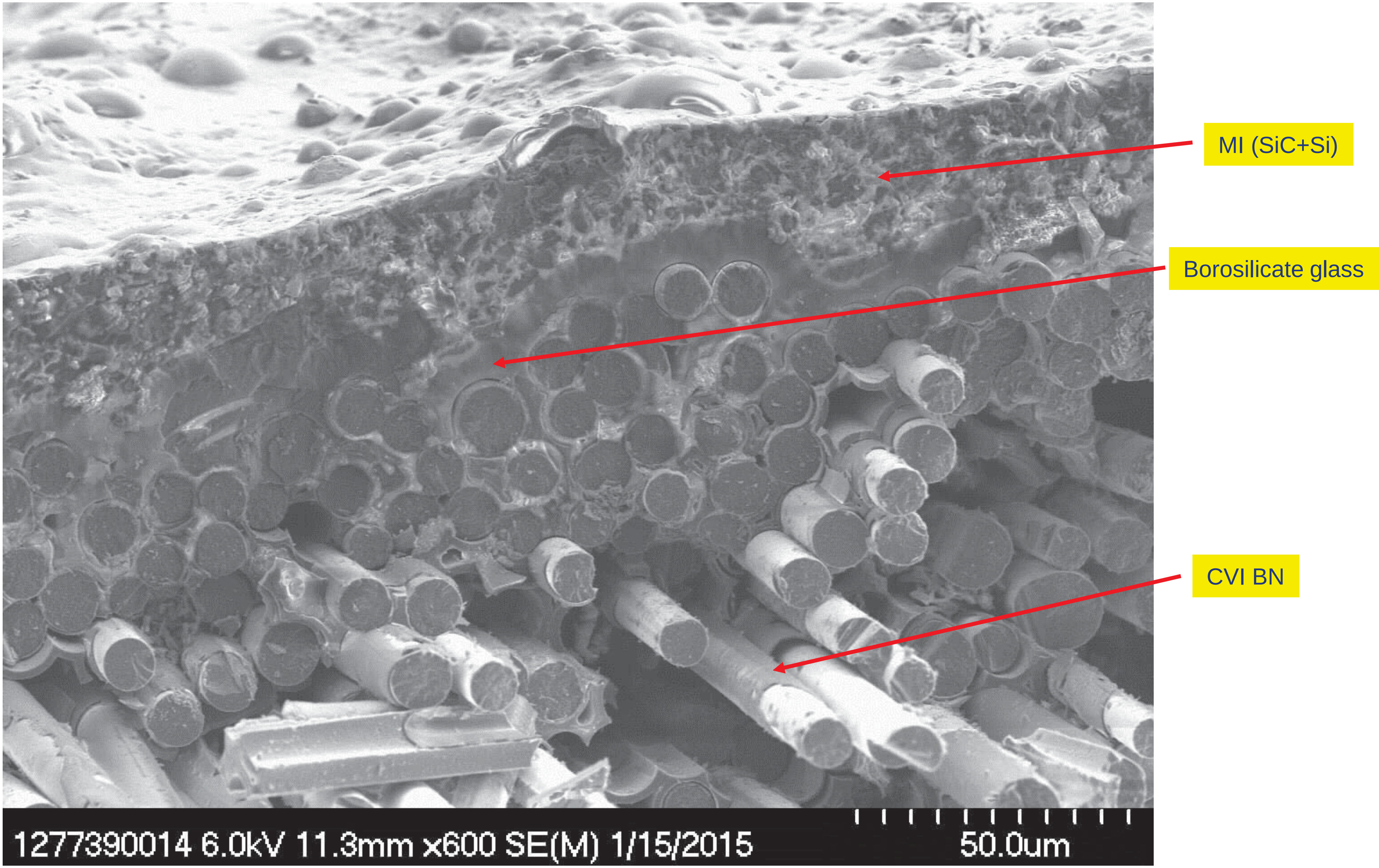
SEM Photograph of Region 1



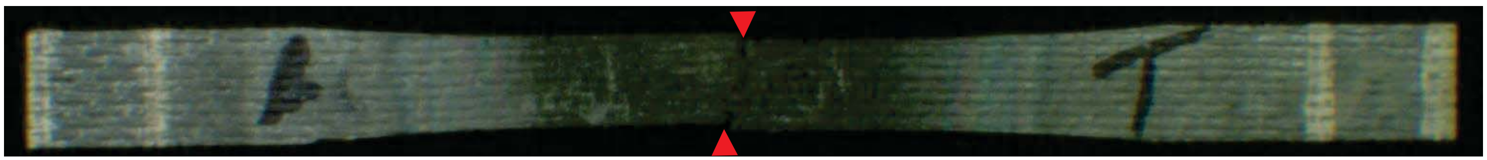
SEM Photograph of Region 2



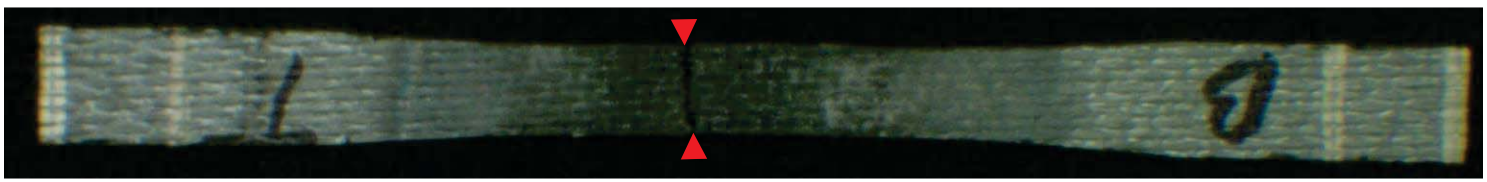
SEM Photograph of Region 3



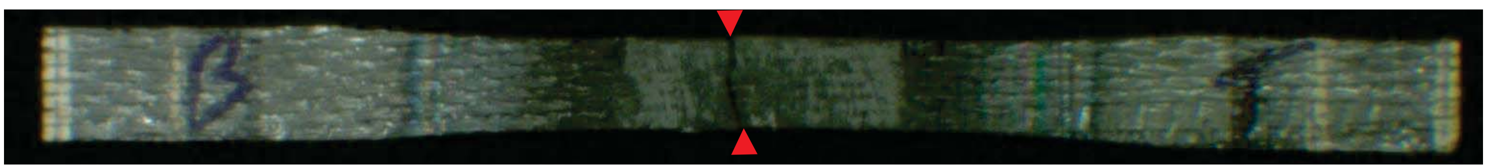
Pre-cracked Uncoated MI Sylramic-iBN SiC/SiC Composite Specimens SPLCF Tested at 1315^{0}C



103MPa/61hrs



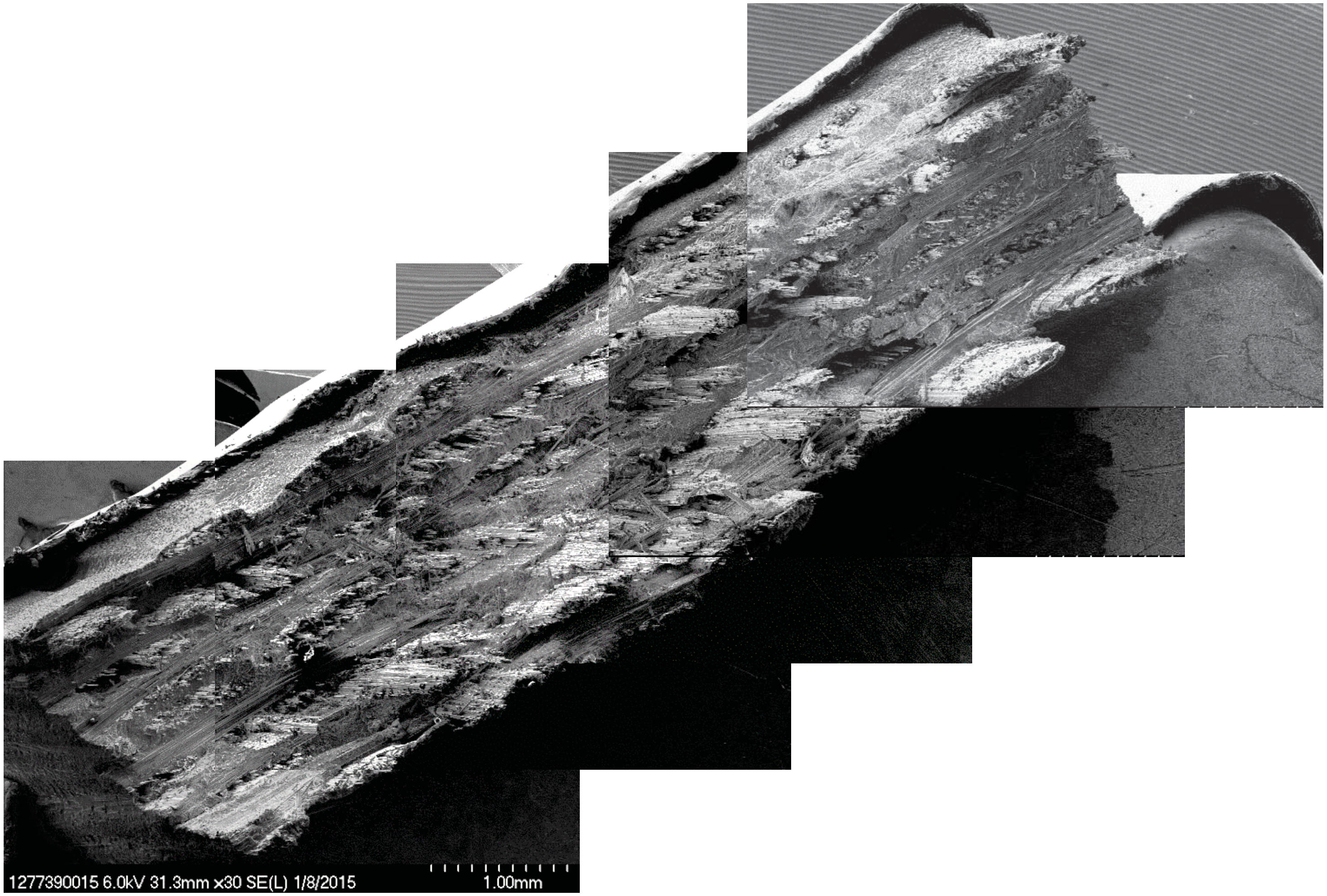
69MPa/150hrs



35MPa/157hrs

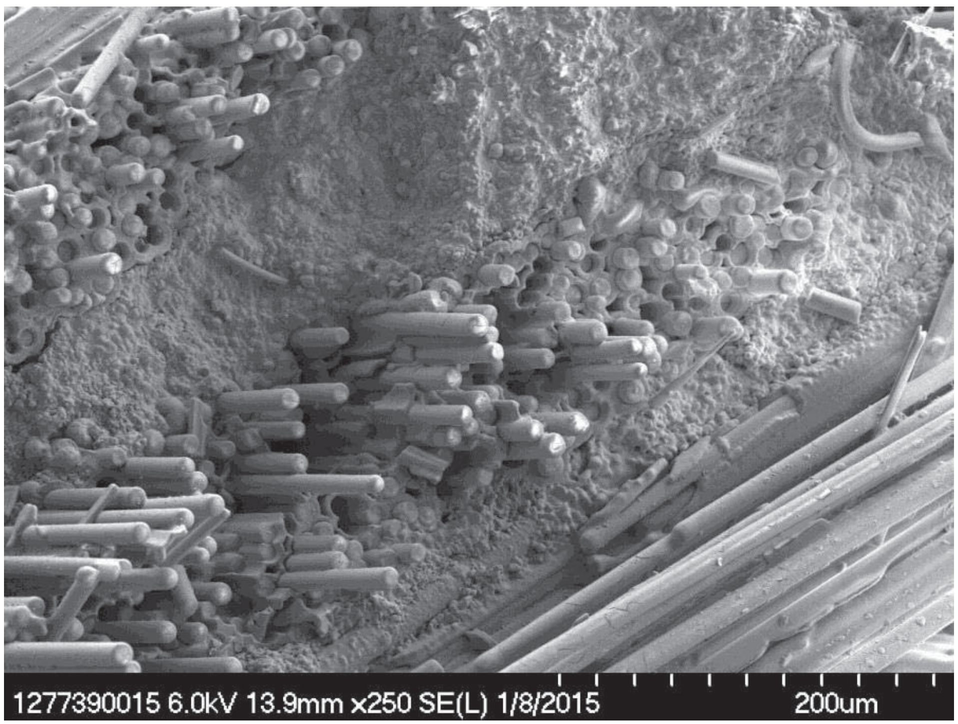
Pre-cracked and SPLCF tested MI SiC/SiC composites failed in the gage section and during the test. The red arrows indicate tensile fractured region.

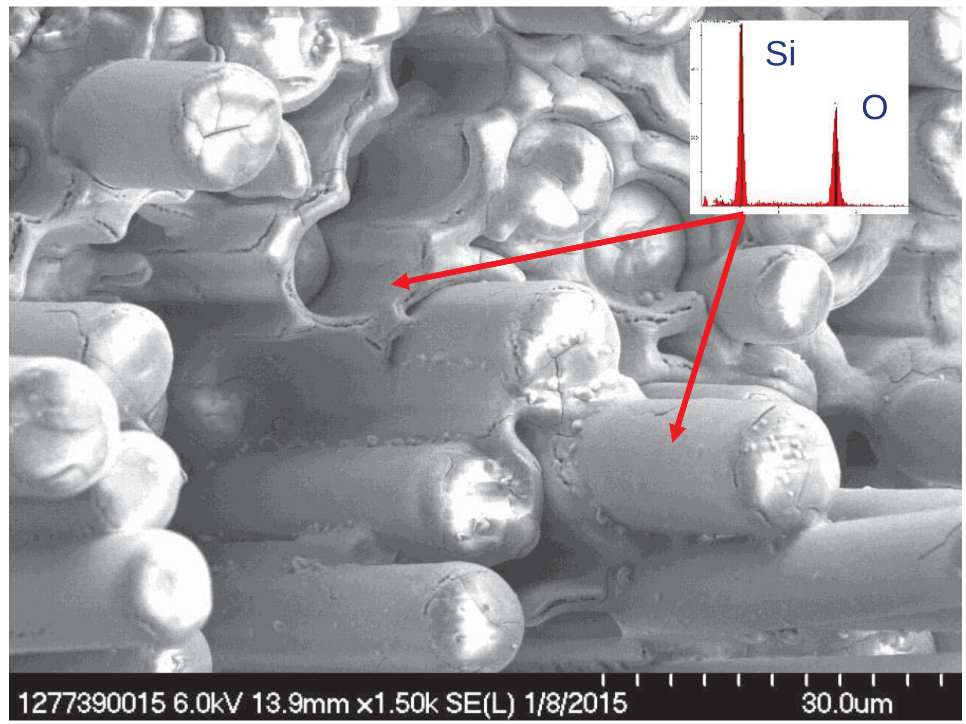
SEM Photographs of the Fractured Surface of a Pre-cracked Uncoated MI Sylramic-iBN SiC/SiC Composite Specimen SPLCF Tested at 35MPa, 1315^0C for 157hrs in Air



Pre-cracked and SPLCF tested MI SiC/SiC composites show shear failure

SEM Photographs of the Fractured Surface of a Pre-cracked Uncoated MI Sylramic-iBN SiC/SiC Composite Specimen SPLCF Tested at 35MPa, 1315^0C for 157hrs in Air

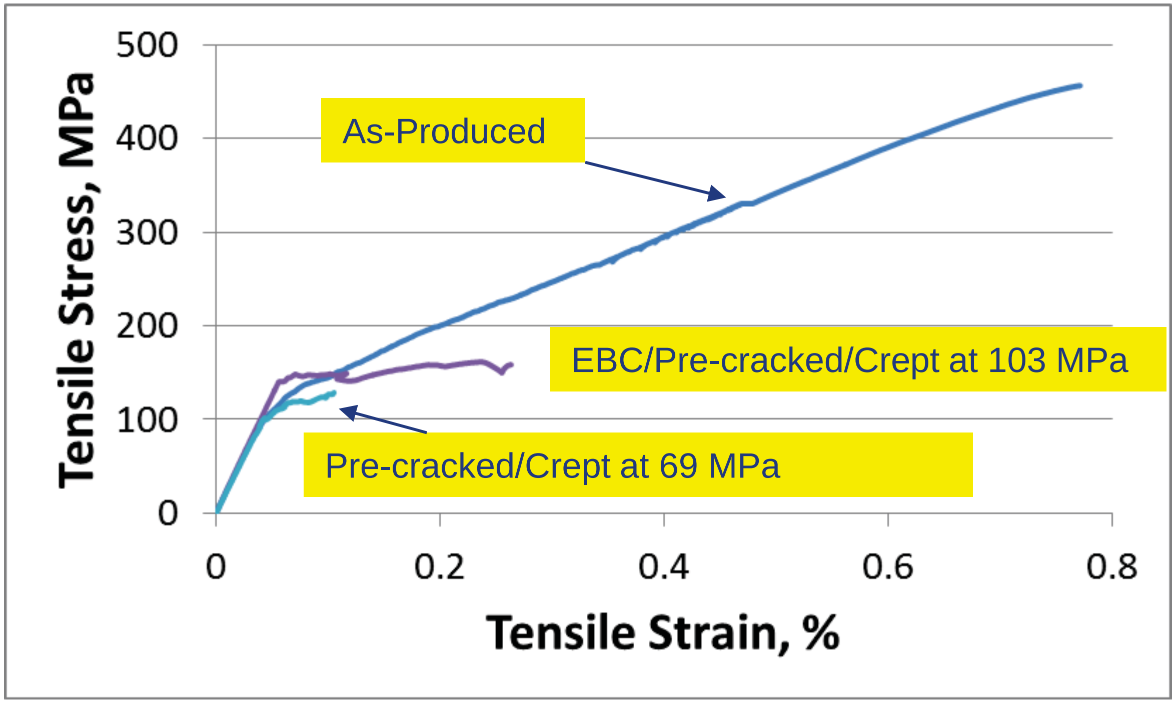




Pre-cracked and SPLCF tested MI SiC/SiC composites failed by extensive interface oxidation followed by fiber fracture.

Room Temperature Tensile Stress-Strain Behaviors of Pre-cracked 2D Balanced MI SiC/SiC Composites With Hi-Nicalon-S Fibers Before and After Creep Test

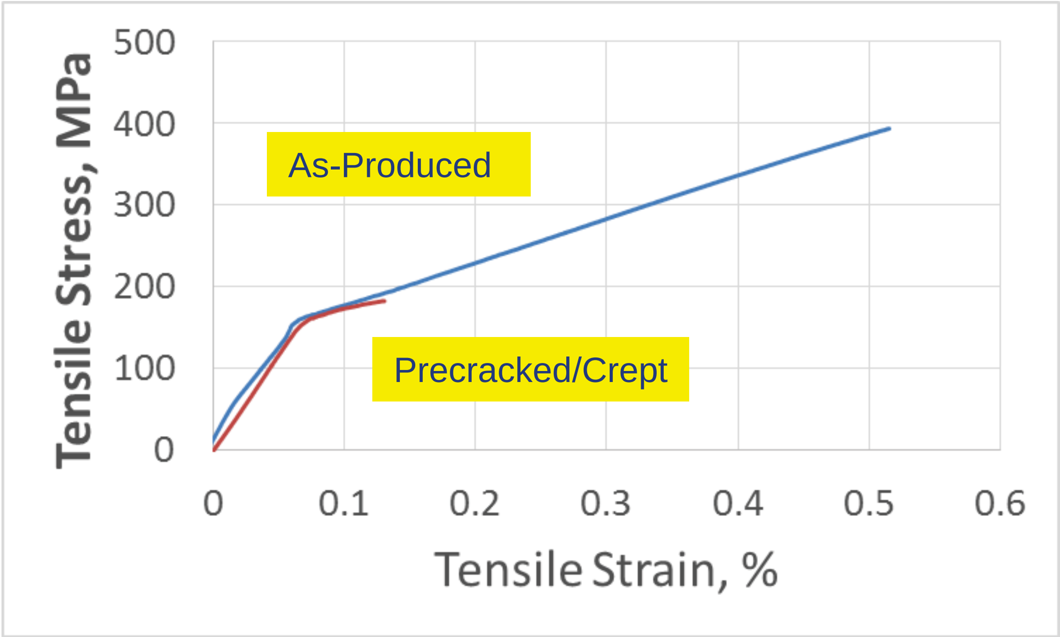
(Burner Rig Creep Conditions: 1315^{0}C/69 and 103MPa/100hrs)



Pre-cracked full CVI Hi-Nicalon-S SiC/SiC composites crept under burner rig conditions survived 100hr exposure, but residual room temperature tensile fracture strengths were low.

Room Temperature Tensile Stress-Strain Behavior of Pre-cracked 2D Balanced Full CVI SiC/SiC Composites With Sylramic-iBN Fibers After the Creep Test

(Burner Rig Creep Conditions: 1315^{0}C/69MPa/100hrs)



Pre-cracked full CVI Sylramic-iBN SiC/SiC composites crept under burner rig conditions survived 100hr exposure, but residual room temperature tensile fracture strengths were low.

Pre-cracked Uncoated and EBC Coated Full CVI Sylramic-iBN and Hi-Nicalon-S SiC/SiC Composite Specimens Creep Tested in Burner Rig at $1315^{0}C$ for 100hrs and then Tensile Tested at Room Temperature

EBC coated full CVI Sylramic-iBN SiC/SiC composite tested at 69MPa

EBC coated full CVI Hi-Nicalon-S SiC/SiC composite tested at 103MPa

Uncoated full CVI Hi-Nicalon-S SiC/SiC composite tested at 103MPa

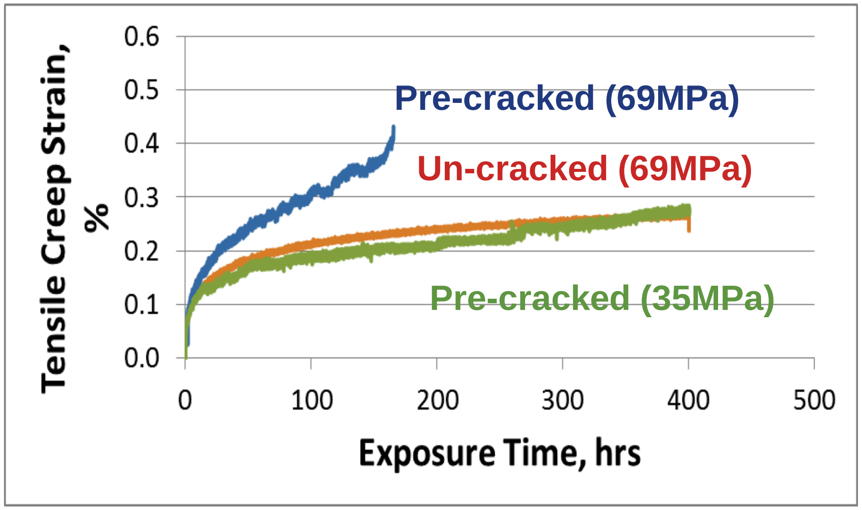
Uncoated full CVI Hi-Nicalon-S SiC/SiC composite tested at 69MPa

Burner rig crept specimens tensile tested at room temperature failed in the gradient region. The red arrows indicate tensile fractured region.

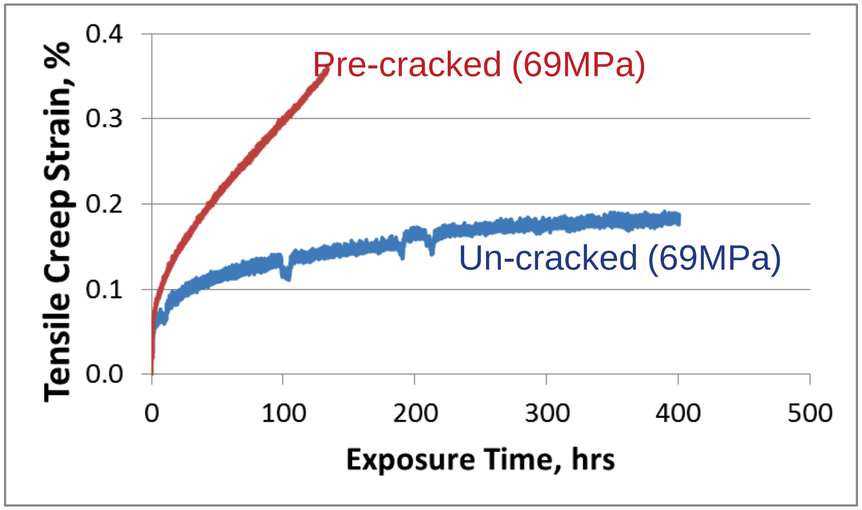
Tensile Creep Behaviors of Un-cracked and Pre-cracked 2D Balanced Full CVI SiC/SiC Composites with Hi-Nicalon-S and Sylramic-iBN Fibers

(Creep Conditions: 1450^{0}C/35 or 69 MPa /Air)

Hi-Nicalon-S Fibers



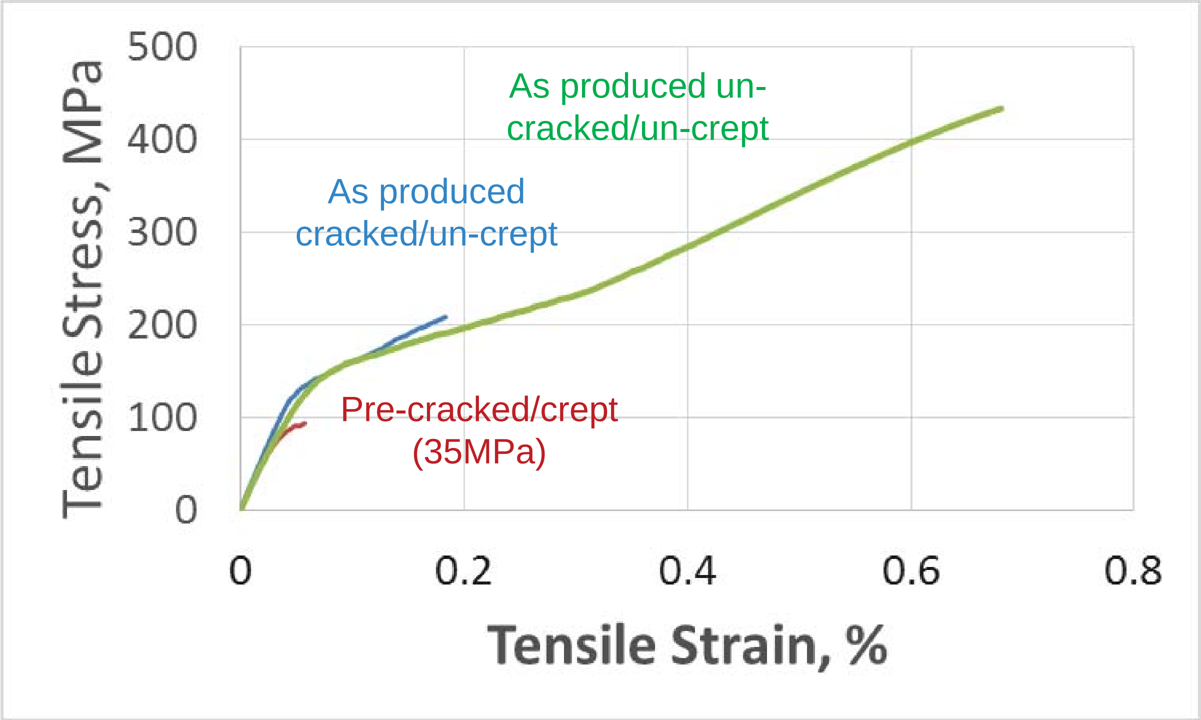
Sylramic-iBN Fibers



Under cracked conditions, the durability of 2D full CVI SiC/SiC composites is significantly reduced irrespective of the type of SiC fiber reinforcement. Also durability of cracked composites depends upon crack opening displacement, extent of crack and the location of the critical crack.

Room Temperature Tensile Stress-Strain Behaviors of Pre-cracked 2D Balanced Full CVI SiC/SiC Composites With Hi-Nicalon-S Fibers Before and After Creep Test

(Creep Conditions: 1450^{0}C/35 or 69 MPa /Air)



In-plane tensile properties of pre-cracked/crept composites are significantly lower compared to those of un-cracked composites. The dominant crack outside the hot section.

Summary of Results

Pre-cracked MI SiC/SiC composites with Sylramic-iBN fibers and full CVI SiC/SiC composites with Sylramic-iBN and Hi-Nicalon-S fibers were tensile creep and SPLCF tested at 1315^{0}C and 1450^{0}C at 35, 69 and 103 MPa for up to 400hrs in air and under burner rig conditions. The failure modes and degradation mechanisms were analyzed by SEM. The key findings are the following.

- **Durability of cracked CMCs is affected by several factors including type of loading, edge effects, location of the primary crack, matrix healing capability and interface coating.**
- **Under creep conditions at 1315^{0}C, the pre-cracked MI SiC/SiC composites exhibit >200hr life and retain >80% of room temperature in-plane tensile properties of as-produced composites. The cracks in these composites healed during creep testing and significantly reduced fiber degradation. Under the same conditions, the full CVI Hi-Nicalon-S or Sylramic-iBN SiC/SiC composites also survive >100hr burner rig or furnace exposure, but in-plane properties are significantly degraded.**
- **Crack growth under creep condition is random, but occurs in the same plane.**
- **Under SPLCF conditions at 1315^{0}C, the pre-cracked MI and full CVI SiC/SiC composites exhibit < 200hr life, shear failure and extensive interface oxidation. Fatigue cracks grow in different planes and then link-up, causing ultimate fracture.**
- **Under creep conditions at 1450^{0}C, pre-cracked full CVI SiC/SiC composites with Sylramic-iBN or Hi-Nicalon-S fibers show short life if the primary crack is in the hot section.**